Course Name: Design of Electric Motors

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Title: Basics of Electrical Machine Windings

Greetings to all. In this lecture, we will discuss the basics of electrical machine windings, like what is the meaning of coil, coil pitch, pole pitch and different type of windings, like short pitch winding, distributed winding, full pitch winding or concentrated winding, slap winding, wave winding. The basics related to all these type of windings, we will discuss. Next, we will see why we require the electrical windings. All rotating electrical machines require two magnetic fields to generate a torque, based upon the attractions and repulsions of these two magnetic fields. It will generate a torque and this is the working principle for any type of electrical machines.

That is what we have concluded in the earlier lectures. So, to create these two magnetic fields, we require the windings. Windings are nothing, but arrangements of or group of a conductors. For example, if you will see the induction motor at the right side corner, stator is a distributed winding and rotor is a squirrel cage winding.

Because of the distributed winding at the stator side and variable fields with AC supply and squirrel cage rotor at the rotor side and based upon the mutual induction principle, the current will be induced in the squirrel cage and there is another magnetic field will be established at the rotor side. The attractions and repulsions of these two magnetic fields, the machine will work. So, these are the different type of windings with respect to the DC machines as well as AC machines. The closed type of windings, we will utilize in DC machines where the commutators and brushes are used. Open type of windings, there is no brushes and commutators.

The closed type of windings are classified into two types, gram ring winding and drum type of winding. The gram ring winding is the oldest winding type with respect to DC machines where half of the windings are participated in the effective energy conversion. Remaining half of the winding are not utilized for torque generation. That means, copper utilization is poor in this winding and here copper utilization in drum type of winding is high. These drum type of windings are classified into lap winding and wave winding.

The only difference is how we are connecting the commutators and brush arrangement with respect to these two windings. With respect to open type of windings are classified into three types. One is concentrated, distributed and musk type of windings. In concentrated windings, all windings are placed at one particular place and we will generate square type of MMF. In distributed windings, the conductors are distributed over n number of conductors and we are seeing the stepped MMF waveform or smoother MMF waveform.

These distributed windings are classified into full pitch winding and short pitch windings, integral slot and fractional slot windings, single layer and multilayer windings. We will see one by one what is the difference and basics related to all these type of windings and mush windings generally utilized in low power machines, where the coil length with respect to the one coil side and other coil sides are different. For example, each coil is a combination of two conductors. The length with respect to one coil side and length with respect to the other coil side is different in this type of mush windings. Only low power applications will utilize it.

First, we will discuss the conductor. Conductor is nothing but a piece of copper wire. We can see here, this is a conductor. What we are placing inside the machine and blue color one is the conductors and what we are placing inside the stator core. We can see here, the conductors we are placing at slot one as well as slot seven and it will take the active part in the energy conversion process.

With respect to the north pole, we are seeing current is entering with respect to the south pole, current is leaving and depends upon the magnetic Orsted principles and thumb rule. We can see the magnetic lines formation and these two conductors along with the overhangs and end rings will act as one magnetic field source. The turn is nothing but combination of two conductors with additive polarity of their MMF. These two conductors are connected with overhang. This is the overhang and we can see here, the pink color one is the overhang and it has only one turn.

If the coil consists of n number of turns, we can see here, the multiple turn coil which consists of n number of turns. All turns are connected in series fashion. Coil has two coil sides which are placed on two different slots. One coil side is placed at the north pole side and other coil side is placed at the south pole side. Physical coil looks like in this fashion.

This is one coil side and this is another coil side. It has two ends. One will be starting and other will be ending. That is represented here. The number of coils depends upon the number of slots inside the stator core and how many coil sides are there in each and every slot.

If one coil side is there in the slot, it will be like this. If two coil sides are there in the slot, it looks like in this fashion. So, how to calculate the total number of coils means that is slots by 2 because each coil we have to place in two slots because of that reason q s by 2 into number of coil sides or layers per slot. Then, number of coils per phase is equal to phase. C total is nothing but number of coils with respect to all three phases. With respect to one particular phase means by number of phases that is by ms and it will give the final expression in terms of slots per pole per phase that is q and number of pole pairs that is p by 2 and number of layers that is n.

In order to calculate the number of coil sides per pole, each coil has two coil sides. We can see here this is one coil side and this is another coil side. In a physical coil, we can see two coil sides here. So, to find the coil sides per pole, total number of coil sides divided by poles.

So, in order to find the total number of coil sides per coil sides, total coils into 2 that will give the coil sides per pole. This expression will give the total coils sides per pole per phase q into n because slots per pole per phase I am considering into number of layers. Number of turns per phase if you want to calculate, this n phase we have to calculate based upon the Faraday's law of voltage equation from there n turns we can calculate. C phase is nothing but number of coils per phase and n coil is nothing but number of turns per one particular coil.

Let us consider an example 24 slot 3 phase 4 pole single layer winding slots per pole per phase is equals to 2 and total number of coils is equals to q s by 2 into coil sides that is single layer winding means 1 coils and coils per phase is by 3 12 by 3 will give 4 here and then coil sides per pole is equals to q into n coil sides per pole per phase that is type of mistake.

So, it will give 2. So, the total coil sides per pole will come 24. So, the total number of coils per pole of coils are 12 12 into 2 24 by 3 into 4 it is coming 2 coil sides per pole per phase and coil sides per phase will be 24 by 3 that is 8 coil sides will be there per pole. If you want to calculate total coil sides by 4 6 coil sides will be there under 1 pole. Now, how to calculate the coil pitch between 2 coil sides? Let us consider a 24 slot stator core and in order to define the coil pitch one reference parameter we will calculate that is the pole pitch. This pole pitch value always constant with respect to this particular value we will define the coil pitch.

Pole pitch is nothing but distance between 2 adjacent poles between the center of north pole to center of south pole those 2 should be adjacent. We can see here and with respect to this one we can see from this point to this point or starting point of the north pole and starting point of the south pole also we can consider and pole pitch is always equals to 180 degrees electrical and coil span is nothing but the distance between 2 coil sides. If it is a coil distance between 2 coil side will give the coil pitch. If the coil pitch is equals to pole pitch or 180 degrees electrical then it the type of winding is full pitch winding. If coil pitch is less than 180 degrees electrical that type of winding is called short pitch winding.

If coil pitch is greater than 180 degrees electrical that type of winding is called as over pitch winding. For an example here pole pitch is equals to 6 slots or 180 degrees electrical for 24 slots and 4 pole winding 24 by 4 will give 6 slots that is the pole pitch. Pole pitch can be represented in terms of slots or in terms of electrical angle 180 degrees mechanical angle means by 2 we have to consider. If the coil pitch is equals to 6 then it is full pitch winding greater than 6 that is over pitch winding less than 6 slots it is short pitch winding. So, here we can see the conductors or coil sides are placed in 1 and 7 that means it is a full pitch winding that is equals to 6 slots.

Next phase spread or phase span the phase spread or phase span is nothing but slots per pole per phase or we can call it as phase belt under 1 particular pole. Let us consider the slots per pole per phase slots per pole first we will consider that is 6 slots are coming 24 slot per pole per phase and 4 pole. So, slots per pole will be 6 right under 1 particular pole how many slots we are dedicating to each and every phase that will give the phase spread. Let us say this is A phase this is B phase and these 2 slots are C phase. So, here slots per pole per phase is nothing but phase belt that is equals to 2.

We can represent in terms of slots or angle. So, that slots per pole per phase we will calculate with respect to the standard equation Qs is equals to number of phases m into number of poles into slots per pole per phase.

So, here we can see the phase spread in electrical always it is 60 degrees because each pole is 180 degrees that means electrically the phase spread with respect to the each phase will be 60 degrees 60 degrees and third one also 60 degrees. So, this phase spread or phase span in electrical 60 degrees will not change. We can see here the phase spread with respect to the A phase is 2 slots under green color pole like each pole having 6 slots.

So, like that 24 slots I have shown here and 1 2 is nothing but 1 phase span and under each and every pole we can see 2 slots are accommodating the A phase conductors. Same way in the right side image all 3 phases are shown each phase is accommodating 2 slots in each and every pole. The windings used in electrical machines are classified as concentrated and distributed windings single layer and double layer windings full pitch and short pitch windings fractional slot and integral slot windings lap winding and wave windings. Lap winding and wave windings generally we will utilize it in DC machines. The lap winding and wave windings are also same as AC type of machine windings.

Only difference is how we are connecting the commutators and brushes arrangement. First concentrated windings we will see where all conductors are placed at one particular place. It has same magnetic axis and the examples we can see inductors, transformers, DC machines, windings and field windings of salient pole synchronous machines etcetera. It generates the square type of MMF waveform and consists of higher harmonics with respect to square wave MMF. We have derived the stator MMF expression with respect to the square wave and concentrated windings.

Harmonics magnitude we can calculate based on that we can analyze what is the and what are the order and what are the magnitudes with respect to different harmonics. Distributed windings instead of placing conductors in one particular place, we are distributing into n number of slots. We can see here the conductors are distributed in n number of slots and an examples we can see here stator and rotor of induction machines and armatures of synchronous machines and DC machines. It will generate a stepped MMF waveforms with reduced harmonics and induced DMF also harmonics will come down and the distribution of conductors helps in better cooling and the core is fully utilized. We can see here the core is fully utilized with respect to the conductors placement.

Then single layer winding, in single layer winding, each slot consists of one coil side. Here one coil side, here also one coil side with respect to north pole and south pole. In double layer windings, each slot consists of two coil sides. This is one coil side that is blue color at the top side, red color at the bottom side, here also same. To make the winding symmetry, the top side conductor is always connected bottom side conductor under south pole.

That is this blue conductor or coil side is connected to the red color that is bottom side to minimize the leakage fluxes as well as to get the symmetrical winding distribution. This red color one that is bottom side coil side placed in the first slot is connected to the top side coil side, which is placed on the coil side, which is placed at the top side under south pole. Multilayer windings where the slot is filled with n number of coil sides. We have seen here two coil sides. Let us say three coil sides or four coil sides up to n number of coil sides.

The advantages with the multilayer windings are any type of winding we can design like integral slot winding or fractional slot winding or different slot numbers also, some new type of windings also possible with multilayer winding. Single layer windings we can see with respect to the 24 slots, three phase four pole machine coil pitch is equals to 6 slots and total number of coils is equals to 24 by 2. It is a single layer winding means into 1. So, 12 coils will come.

The 12 coils are placed in 24 slots. We can see here all 24 slots are filled with 24 coil sides. Full pitch winding means the coil side, which is placed in the slot 1 is connected to the slot 7. That is 1 plus coil pitch 6 is equals to 7 and same way 2 plus 6 is equals to 8 or 2 minus 6 is 6. For symmetrical winding distribution, some windings will make it forward and some windings will connect in backward direction. That we will discuss in detail in the coming lectures.

2 minus 6 will give minus 4 plus 24 will give 20. So, second slot, the coil side is connected to the coil side placed in the slot number 20 with respect to the first coil side 1 and 7 are connected. The coil sides placed in the slot 1 and slot 7. Once we have done the coil, we have to place this coil side in slot number 1 and this coil side in slot number 7. This side 1 and this is 7 and same way second coil, we have to place in slot number 2 and slot number 20.

Third coil slot number 8 and slot number 14. We can see here third coil, we are placing in slot 8 and slot 14. Fourth coil slot number 13 and slot number 19, we have to place in this fashion. Next double layer windings, same example 24 slots, 3 phase, 4 pole winding, coil pitch is equals to 6 that is distance between 2 coil sides and total number of coils will come now 24 because of the double layer winding. So, as per the coil pitch and it is a full pitch winding, 1 plus 6 equals to 7 will come. So, after making the coils with 6 coil pitch, one coil side we have to place in slot 1 top side.

We can see here this is the slot 1 and this is slot 7. First slot top side and seventh slot bottom side, we have to place the first coil. Second coil same way, second slot top side, eighth slot bottom side. We can see here the 1 and 7 dash, 1 and 7 dash and 2 and 7 dash.

8 dash, already we have done the coil. We have to place at this location and at this location first coil. Second coil will be at this place and at this place. So, this coil side and this coil side that is it. We have to insert one by one and same fashion. We can place the all 8 coils with respect to the double layer winding.

Next full pitch winding, short pitch winding and integral slot and fractional slot windings, we can define with respect to the variable that is slots per pole per phase. If the slots per pole per phase q value is equals to 1 or integer and coil pitch is equals to pole pitch, then that type of winding is called integral slot full pitch winding. If q equals to integer or equals to 1 and the coil pitch is less than the pole pitch, then that type of winding is called integral slot short pitch windings. If q value is a fraction like 3 by 2, 5 by 2 like that and coil pitch is equals to pole pitch, then that type of winding is called fractional slot full pitch winding. q equals to fraction and coil pitch is less than pole pitch.

That type of winding is called fractional slot short pitch windings. The advantage with respect to the short pitch windings over the full pitch winding are saving of the copper due to the end ring connections and reduction of harmonics with respect to the EMF and MMF waveforms and advantages of fractional slot windings over the integral slot windings are flexibility to select any type of any type or any number of slots as well as coil span and reduction of harmonics in EMF as well as MMF waveforms. We can see here the 24 slot stator core and how the coils are placed. First, we will discuss with respect to the full pitch winding. Full pitch winding means directly 1 plus 6 is equals to 7 and 2 plus 6 or 2 minus 6, we can connect 1 to 7 and 2 to 20.

These things are already discussed after making the coil. One side we have to place in slot number 1, other side we have to place in slot number 7. Same way, second coil side we have to place in second slot and second coil side we have to place in 20th slot. Short pitch winding where the coil pitch is 5 slots only, it is a short pitch by 1 slot and coil pitch is equals to 6 minus 1 slots and where in short pitch windings, the pole pitch is higher than the coil pitch. In full pitch winding, the coils we are placing in slot number 1 and slot number 7.

Now, 1 plus 5 only we have to place. 1 plus 5 is coming 6, but already in 6th slot, C phase conductors are placed some other conductors because with respect to one particular pole that is green color 1, phase spread should be 2 slots, all 3 phases. These 2 slots with respect to A phase, these 2 slots with respect to B phase and these 2 slots with respect to C phase. To make the short pitch winding, 1 plus 5 is not possible. 1 minus 5 we will do that is minus 4 plus 24, it will give 20. So, we have to place the coil this one, 1 coil side in slot number 1, other coil side should be slot number 20.

So, conductors in slot number 1 and 20 are connected. 2 and 7 are connected. Same fashion 8 and 13 and 14 and 19. Here, we can see coil pitch is equals to 5, whereas in the other case coil pitch is equals to 6. Now, integral slot winding is nothing but the slots per pole per phase will give a integer either 2 or 3 or any integer it will come. So, the coil pitch will be same whether it is full pitch winding or short pitch winding based upon that thing, we have to make the coil pitch and we have to place the coil sides accordingly.

Here for example, full pitch and double layer winding. So, the first coil let us say this is the first coil. So, we have to place this coil side in slot number 1, top side that is this one and next coil side we have to place in slot number 7 bottom side. These 2 are connected. Same way 2 to 8 dash, then 7 to 13 dash, 8 to 14 dash like that it will go while discussing the integral slot winding diagrams, we will discuss in detail these things and fractional slot windings 18 slot 3 phase 4 pole machine and slots per pole per phase is coming here fraction and we can see the coil pitch 4.

5. It is also a fraction number and 4 or 5 we can take it. If you are taking 4, it is a short pitch winding. If you are taking 5, it is a over pitch winding slightly and number of coils is equals to 18 by 2 into 2. It is double layer winding. Otherwise, this winding is not

possible because the fraction it is coming slots per pole per phase. We have to distribute each phase will be one half slots in each and every pole.

We can see under one pole 4 and half slots are coming. So, one and half slot related to the A phase remaining one and half slot related to the B phase and remaining one and half slot for C phase like that we have to split the portions with respect to the all 3 phases and we have to place the coils. The A phase coils we can see here with respect to the red color representation 1 and 2. So, 1 and 1 dash and second slot 2 like 3 coils are placed under one pole. Each and every pole 3 coils are there. So, the first coil side we will place in 1 and next coil side we will place at 5 dash 1 plus 4 is equals to 5.

Next 2 plus 4 is equals to 6 like this we will go. If forward manner is not possible, then we have to come back either 1 plus 4 or 1 minus 4 we can connect it. Then DC type of windings in DC machine windings, we will utilize the closed type of windings like lap winding and wave winding. The only difference is how we are connecting the conductors with respect to the commutators and brush arrangement. The number of coils equation and coils terminology with respect to coil pitch pole pitch and other terminology is same as AC machines.

The only few terms are different. Those terms we will discuss in the coming slides and the number of commutators depends upon the number of coils and here also short pitch winding, full pitch winding and over pitch windings. We can see if the coil pitch is equals to 180 degrees or less than 180 degrees or greater than 180 degrees. Based on that we can classify these 3 types of windings and right side we can see the 2 coil sides. One coil side placed with respect to the one pole and other coil side is placed with respect to the others pole and those 2 are connected to commutator rings.

We can see here the 2 commutator rings. These are the 2 commutator rings and bottom side 4 coils and 4 commutator segments are shown with respect to 4 pole winding of DC machines. The pitch terms in DC machines, let us consider the few coils like coil 1 is placed in slot number 1 and slot number 4 and coil 2 is placed in slot number 2, top side and slot number 5 bottom side and coil 3 is placed slot number 3 top side that is this one and slot number 6 bottom side 6 dash. Now, the back pitch is nothing but the distance between 2 active sides of same coil under the adjacent opposite poles. We can see this is the starting point and this is the ending point of the first coil. So, with respect to the slot 1 and slot 4 bottom side, we have connected the first coil that is red color 1.

With respect to the red color 1 here, this point and this point, the pitch is nothing but back pitch. From this point to this point is nothing but back pitch. Next, the distance between 2 coil sides connected to the same commutator segments or starting of 1 second coil to ending of first coil. We can see the second coil starting, here second coil starting the laser pointer and first coil ending are connected to the second commutator segment.

This is the second commutator segment. Those 2 windings are connected. That pitch is nothing but front pitch. The resultant pitch is nothing but the distance between starting ends of 2 consecutive coils. The starting end of first coil is 1 and starting end of second coil is 2. The distance between coil 1 and coil 2 is nothing but resultant pitch. We can see here the pink color arrow that is coil 1 with respect to slot 1 top side and slot 2 top side.

This is the pink color representation is y resultant pitch. Then the commutator pitch is nothing but it is the distance between the commutator segments where the 2 ends of the coils are connected. For example, coil 1 is connected to 2 commutators. Let us say C 1 and C 2. The starting end of the coil is 1 and ending point of the coil 1 is 4 dash.

These 2 coil sides are connected to commutator 1 and commutator 2. We can see here. So, the distance between these 2 commutators is nothing but commutator pitch. I am showing with arrow here cursor. So, to design the lap winding and wave winding, we have to follow certain guidelines. So, the lap winding is nothing but it is successive coils overlap each other and front pitch and back pitches values like y b and y f should be odd numbers and must be differed by multiples of 2.

That means, y b minus y f is equals to some 2 or 4 or multiples of 2 should be there and difference of front pitch and back pitch will give the resultant pitch and number of poles is equals to number of parallel paths is equals to number of brushes in lap winding. In lap winding, the 2 ends of the coils are connected to the adjacent commutator segments and if the back pitch is greater than front pitch, then that type of winding is progressive winding. Also, with respect to the commutator pitch equation, if plus sign with respect to the m parameter, it is progressive winding minus sign with respect to the m in commutator pitch equation. That is the retrogressive winding where m is nothing but integer to design the multiplex winding like simplex, duplex or threeplex windings. In lap winding, we will also call it as a parallel connected winding with respect to the commutator connections and it is generally used for high currents and low voltage applications.

We can see here few equations related to the lap winding like the number of coils, back pitch, front pitch and resultant pitch in terms of total number of coils and number of poles and k is nothing but integer to make the back pitch as well as front pitch as a odd number. MC represents what type of winding we are developing, either it is simplex lap winding or duplex lap winding like that and commutator pitch and resultant pitch also we can calculate in terms of m and in terms of front pitch and back pitches.

We can see the front pitch and back pitch and commutator pitch in this image. So, by following these equations as well as these guidelines of lap winding, we can develop the different winding structures for DC machines. If the single line or developed diagram with respect to the horizontal manner, we can see here the front pitch is nothing but starting end of first coil.

Sorry, back pitch is nothing but starting end of first coil to ending point of the first coil is nothing but back pitch. It is shown a blue color and front pitch is nothing but starting end of second coil to ending end of first coil or the coils which are connected to the same commutator segment that is two is nothing but front pitch and back resultant pitch is nothing but distance between two coil sides and commutator pitch is nothing but distance between two commutators to those two commutator segments. The starting as well as ending of the same coil has to be connected. This is progressive winding where the first coil is here and second coil and third coil in forward manner.

We are connecting the winding in the retrogressive winding. First coil will be here. The starting end of second coil will be coming here. So, it will go in this fashion. This is the starting end of second coil. We can follow from here. If we will take this coil as first one, then it is coming back in this fashion and it will reach this one.

It is going in this direction, the starting terminal of first coil, second coil, third coil. In retrogressive winding, starting end of first coil, then second coil, then third coil in this manner, it is going. Whereas, in progressive winding 1, 2, 3 like this, the starting ends of coils are moving. We are making the winding in that fashion.

Similarly, for designing the wave winding, certain guidelines we have to follow. In wave winding, only two parallel paths are provided between the positive and negative brushes and total number of coils will be same. The finishing end of first coil under one pole pair is connected to the starting end of the coil under next pole pair. The front pitch and back pitches should be odd numbers and it should be the deferred by two or equal in some cases. The addition of front pitch and back pitch will give the resultant pitch here. The number of brushes and current collecting paths are always equals to 2 for any number of poles.

Here also, progressive winding, retrogressive winding depends upon the sign with respect to the winding design factor that is m, whether we are designing the simplex winding or duplex winding based on that thing. This type of windings will utilize it for low current and high voltage applications. Same way, here also, few equations to design the wave winding, back pitch, front pitch and resultant pitch, commutator pitch and number of coils. By utilizing these equations, we can develop the wave winding thing. So, here, C total is nothing but total number of coils and q s is nothing but stator number of slots and C p is nothing but number of poles, y b is back pitch, y f is front pitch and y is nothing but resultant pitch.

The equation for resultant pitch is equals to 2 into total number of coils plus or minus 2 into m c. m c is nothing but integer to design the multiplex winding divided by pole pitch and commutator pitch is nothing but half of the resultant pitch. This equation will come. So, same way, with respect to the wave winding, we can see the front pitch and back pitches.

So, the back pitch from this point to this point. So, we can see from this point to this point is back pitch and from this point to this point is the front pitch. Addition of front pitch as well as back pitch will give the resultant pitch that is shown in pink color line here. Commutator pitch is nothing but y c, the distance between the commutators, where the starting and ending of the same coils are connected. We can see in this image, the resultant pitch is the pink one that is distance between this point to this point, the starting ends of the two coils. Back pitch is nothing but blue color one that is starting and ending of the same coil and result front pitch is nothing but ending of first coil to starting of second coil.

If we will see the progressive and retrogressive winding after completion of one wave winding in this fashion, the next end of this thing will come here. If we will consider this is first coil set, the second coil set will come here in the progressive winding, first coil set, second coil set like that fashion. So, we can see here, the first coil starting point will be this one, first coil set and the next coil set will come at this particular point. Then we can see here, the green color one that is this one.

So, that same ending is coming at this particular point and it is starting. So, this is first coil set, second coil set. It is in this direction. In the retrogressive winding, the coil sets are connected in a backward direction. So, the first coil is coming here at this particular place and the second coil with respect to the ending of first coil is shown here in a green color fashion.

This is this one. So, the second coil starting will be this thing. In a backward direction, it will go for retrogressive winding same as the retrogressive lap winding. Here also, the connections with respect to the coil sets will go backward manner. In progressive, connections with respect to the coils will come in a forward manner. Now, we will discuss the generalized procedure to design any type of winding for any type of machine. First, we have to analyze the data with respect to the number of slots, number of poles and number of phases and speed, voltage and power rating and power factor, etcetera.

Next, define the type of winding like concentrated windings or distributed windings, whether it is short pitch or full pitch or lap winding or wave winding. That thing we have to define and which type of winding we are designing based on that slots per pole per phase. We have to calculate once the slots per pole per phase is calculated. Next, we have to calculate the number of turns per phase by utilizing the Faraday's law of voltage equation for a given voltage, power, power factor and flux density and winding factors terms and etcetera.

So, substituting all these numbers and we have to calculate the number of turns. Next, copper wire gauge selection with respect to the given current rating and given power rating. What is the I phase RMS? Based upon the I phase RMS value, we can calculate the cross sectional area of the conductor. Once we know the cross sectional area of the conductor, we can select the appropriate gauge SWG value. Then make the number of coils, let us say 24 slot machine is there and total 12 coils are there.

So, first make all 12 coils with respect to the coil pitch and pole pitch as per the winding diagram. Make the coils, all 12 coils we have to make. Then, we can place one by one and window area check. We have to verify, let us say in each slot, we have to keep 100 number of turns. So, that 100 turns whether we are able to place inside the slot or not with respect to the slot area, we have to calculate.

Always the slot area into window factor should be greater than the number of turns per slot. It is number of turns per slot into area of cross section of each conductor because the slot area is combination of conductors area as well as liners along the slot and separators. We can see along the slot, some insulating paper will be there and there is a separator and closers and wooden piece for the closing the slot. All those things will have to be considered for calculating the slot area because of that reason, we can consider here window factor to accommodate the n number of conductors per slot. Placing the conductors as per the symmetrical winding distribution and stubbing method with arrow check representation to make the connections with respect to all phase windings and verification of magnetic poles formation with respect to the right hand thumb rule principles and winding check like after placing all coils and after arranging all connections, whether is there any short circuit with the winding to body or winding to winding or winding to neutral, we have to verify.

If there is no short circuit, then we can take the six terminals out and we can complete the windings. Why six terminals means to make the star or delta connection for DC machines, only two terminals will come out and testing the machine with respect to the required operating conditions. This is the winding procedure to design the winding for any type of machine. With this, I am concluding this lecture. In this lecture, we have discussed the basics related to the electrical machine windings like coil, coil pitch, coil span and different type of windings. Thank you.